# Searching for Variable Stars in the Central Part of the Globular Cluster M22

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ABSTRACT

Time-series data taken with the Hubble Space Telescope of three fields covering the central part of the globular cluster M22 have been analyzed in search of variable objects. We report identification of 11 periodic variables of which 8 are new discoveries. The sample includes 5 certain contact binaries as well as 1 SX Phe star. Two objects with periods longer than 1 day are preliminarily classified as either spotted variables of BY Dra type or ellipsoidal variables. The most unusual of the identified variables, M22_V11, has $I_C \approx 19.9$ and is located far to the red of the main sequence in the cluster color-magnitude diagram. It shows variability with a period as short as $P \approx 0.066$ days or alternatively with $P \approx 0.132$ days. We propose that it may be an ellipsoidal variable harboring a degenerate component.

*globular clusters: individual: M22 – binaries: eclipsing – – stars: variables*

## 1 Introduction

M22 (NGC 6656) is a bright and rich globular cluster projected against the outer part of the Galactic bulge. Clement *et al.* (2001) list 79 variable stars known to date in the cluster field. Most of them are RR Lyr stars or red long-period variables. Several SX Phe stars and candidate eclipsing binaries were recently identified by Kaluzny & Thompson (2001).

The cluster is located about one-third of the way between the Sun and the Galactic bulge. This makes it an interesting target for observations aimed at detection of microlensing events. Recently Sahu *et al.* (2001) presented results of such a survey which was made in 1999 with the HST/WFPC2. All but one candidate event reported in that paper were, however, later on dismissed as spurious detections triggered by cosmic rays (Sahu *et al.* 2002).

## 2 Observations and Data Reduction

The analyzed data were taken by the HST with the WFPC2 camera starting on 1999 February 22 and ending on 1999 June 15, as a part of the GO 7615

program. Three fields covering the central region of M22 were observed. Their location is shown in Fig. 1. Among 43 observations available for each field 31 were made in the F814W filter and 12 were made in the F606W filter. For both filters every individual observation consist of a pair of adjacent 260 s exposures. Our search for variable objects was based solely on the F814W images for which average time resolution equals to about 3.6 days.

Data reduction were performed using the HSTphot stellar photometry package (Dolphin 2000a, Dolphin 2000b). Before extracting photometry we performed some image processing steps, like masking bad pixels and cosmic-ray rejection. The latter step was based on comparison of the two adjacent images each forming an individual observation. The profile photometry was obtained using a library of model point-spread functions PSFs supplied along with the HSTphot package. The code was run with the "option" parameter set to 512. It was found, after some tests, that such a selection allows to obtain most reliable results in comparison with other possible values of "option". Photometry for the F814W filter was transformed to the standard $I_C$ system using the utility available in the HSTphot package.

Before constructing light curves for all detected stars we performed elimination of some potentially poor measurements which could lead to detection of spurious variability during subsequent analysis. First we removed all objects with $\chi > 7.0$ and $|sharpness| > 0.4$ (see Dolphin 2000a for definition of these two parameters). As the next step we prepared for each field a set of masks covering images of badly saturated stars. The shape of each mask consists of a central disk and a cross filling diffraction spikes. Objects located in regions covered by these masks were removed from further considerations. For each field about 20% of objects detected by HSTphot were eliminated as a result of two above described steps.

Subsequently, we selected a reference image for each of the six filter and field combinations and calculated the median value of the magnitude offset for each individual frame in respect to the reference image. These offset corrections amounted in all cases to values smaller than 0.02 mag. Finally we constructed light curves for all stars retained on lists corresponding to the reference images. The overall quality of photometry derived for the $I_C$-band is illustrated in Fig. 2. In that figure we plot the rms deviation versus average magnitude for the light curves of objects from the sub-field B.

Light curves containing at least 24 data points were analyzed in a search for variable stars. The search was performed with the TATRY code using the multi-harmonic periodogram of Schwarzenberg-Czerny (1996). Periodograms were calculated for periods ranging from 0.01 to 100 days. The

later period corresponds to time span of observations. After accounting for some overlaps between observed fields the total number of analyzed objects amounts to 44800. For each of three surveyed fields light curves of about 300 most probable candidates for variables selected with the TATRY were examined by eye.

## 3 Results

Our search for variable stars led to detection of 11 certain variables. Their equatorial as well as rectangular coordinates measured in the reference images are listed in Table 1. Three out of eleven detected variables, M22_01, M22_02 and M22_03 were previously found by Kaluzny and Thompson (2001) and they are listed in their paper as V27, V13 and V43, respectively. We note that the surveyed field includes also some other known variables. However, images of these relatively bright stars were saturated on the analyzed WFPC2 frames. Moreover, we have not recovered a candidate cataclysmic variable detected originally by Sahu *et al.* (2001) and discussed more recently by Anderson *et al.* (2003). On several frames images of that object were affected by saturated pixels and as a result its light curve obtained by us contained too few data points to be included in the sample of objects examined for variability.

Table 2 gives some basic photometric data on all identified variables. Instrumental magnitudes F606W at maximum light are estimated from phased light curves including at most 12 data points. Proposed classification of variables is given in the last column of Table 2. Their phased as well as time-domain $I_C$ light curves are presented in Fig. 3. Fig. 4 shows the location of variables on the $I_C$ versus F606W-F814W color-magnitude diagram of the cluster.

Light curves and periods of stars #2-6 are typical for W UMa-type contact binaries. Also their positions on the color-magnitude diagram are consistent with such a classification. We note parenthetically that star #3 exhibits total eclipse. Variables #7-8 show periods falling into the range occupied by contact binaries. However, their light curves show minima too wide for W UMa-type stars. Moreover, star #7 is located to the blue of the cluster main sequence, which would be unusual for a contact binary belonging to the cluster. At present, secure classification of variables #7-8 is difficult but we note that their periods may be in fact twice as short as those listed in Table 2. Objects #9-10 can be classified either as BY Dra stars or

as ellipsoidal variables. In the latter case their periods would be twice as long as the values given in Table 2. In such a case phased light curves of the variables would show two maxima and would resemble light curves of ellipsoidal variables.

Variable #11 is potentially the most interesting of all variables reported in this contribution. It shows a sine-like light curve with an amplitude of about 0.16 mag and a period of $P = 0.066$ days. This type of variability would be consistent with classifying the variable as a pulsating SX Phe star. However, SX Phe stars are always located among blue stragglers on color-magnitude diagrams of their parent clusters. As seen in Fig. 4, variable #11 is too faint and too red to be classified as an SX Phe star belonging to M22. We have considered the hypothesis that this variable is in fact a highly reddened background SX Phe star. The cluster reddening is estimated at $E(B-V)=0.34$ (Harris 1996), while according to Schlegel *et al.* (1998) the total Galactic reddening in the cluster direction amounts to $E(B-V)=0.33$. Comparison of these numbers indicates that any star located in the cluster field can hardly be more reddened than the cluster itself. Hence, the red color of star #11 is its intrinsic property and therefore it cannot be classified as candidate SX Phe star. The observed period of the variable falls within the range of orbital periods observed for cataclysmic variables (CVs). However, its red color is rather unusual for an active CV. We propose that star #11 is in fact an ellipsoidal variable composed of a red dwarf and a compact low-luminosity companion. An example of such type of objects are "hibernating" cataclysmic variables, progenitors of millisecond pulsars or X-ray transients harboring millisecond pulsars. A separate issue is cluster membership status of the variable. As can be seen in Fig. 4, #11 occupies a position far to the red or alternatively far above main sequence of the cluster. That suggests that it is just a foreground object not related to the cluster. On the other hand the example of J1740-5340 in NGC 6397 (*e.g.*, Ferraro *et al.* 2001) tells us that optical companions to millisecond pulsars can be located to the red of the main sequence on the color-magnitude diagrams of their parent clusters. In that context, it would be worth to check the membership status of #11 by determining its proper motion relatively to the bulk of M22 stars. As was demonstrated recently by Anderson *et al.* (2003), the available archival HST/WFPC2 data make such a determination feasible for a fraction of the M22 core. Unfortunately, examination of the HST/WFPC2 archive shows that for the moment it contains only two sets of images including M22_V11. Besides the 1999 images analyzed in this paper, the variable can be located on a set of 26 s images collected in 2000. The shallowness of the 2000 data

Table 1: Equatorial coordinates and $(X,Y)$ positions of variables on the HST/WFPC2 images

| Name | RA(2000.0) [h:m:s] | Dec(2000.0) [° :′:″] | Field | Chip | Location $(X,Y)$ | Dataset name |
|---|---|---|---|---|---|---|
| M22_01 | 18:36:22.49 | -23:55:12.9 | C | PC1 | (557,778) | u5330105r |
| M22_02 | 18:36:30.81 | -23:53:46.1 | A | WF3 | (121,527) | u5330101r |
| M22_03 | 18:36:24.21 | -23:56:19.4 | C | WF4 | (336,630) | u5330105r |
| M22_04 | 18:36:22.79 | -23:52:48.3 | B | WF2 | (230,637) | u5330103r |
| M22_05 | 18:36:22.26 | -23:54:32.9 | C | WF2 | (669, 78) | u5330105r |
| M22_06 | 18:36:25.19 | -23:54:37.3 | C | WF2 | (331,308) | u5330105r |
| M22_07 | 18:36:26.89 | -23:53:43.3 | A | WF4 | ( 97,290) | u5330101r |
| M22_08 | 18:36:24.17 | -23:54.10.1 | C | WF2 | (616,425) | u5330105r |
| M22_09 | 18:36:29.99 | -23:55:42.8 | C | WF3 | (246,698) | u5330105r |
| M22_10 | 18:36:27.12 | -23:52:59.7 | A | WF2 | (262,137) | u5330101r |
| M22_11 | 18:36:30.32 | -23:55:23.0 | C | WF3 | (426,601) | u5330105r |

as well as the short time base of two available epochs makes determination of the relative proper motion of M22_V11 problematic.

## 4 Conclusions

Our search for variable stars in the globular cluster M22 leads to the detection of 11 certain periodic variables. A small number of observations, consisting of just 31 magnitudes spread over almost a 4 month period, indicates that our sample is highly incomplete. In fact, all identified objects show continuous variability which makes their detection far easier than detection of variables with a short duty cycle, such as detached eclipsing binaries. Considering the small number of available observations, we decided that it was pointless to conduct any simulations aimed at deriving quantitative estimates of completness of derived sample of variables.

Results of the astrometric study conducted by Anderson *et al.* (2003) indicate that inside the surveyed HST/WFPC2 field, the cluster stars prevail strongly over field objects. That suggests that most of detected variables belong to M22. However, dedicated astrometric reductions extending the results of Anderson *et al.* (2003) to the remaining 3 WFPC2 chips would

Table 2: Photometric data for the M22 variables

| Name | $I_{C,max}$ | $\Delta I_C$ | F606W$_{max}$ | $P$ [d] | d$P$ [d] | Type |
|---|---|---|---|---|---|---|
| M22_01 | 16.23 | 0.07 | - | 0.042171 | 0.000002 | SX Phe |
| M22_02 | 16.46 | 0.41 | 17.36 | 0.281699 | 0.000012 | EW |
| M22_03 | 17.37 | 0.38 | 18.31 | 0.220502 | 0.000005 | EW |
| M22_04 | 18.46 | 0.32 | 19.77 | 0.312263 | 0.000016 | EW |
| M22_05 | 17.25 | 0.19 | 18.15 | 0.242792 | 0.000007 | EW |
| M22_06 | 17.14 | 0.47 | 17.98 | 0.239431 | 0.000005 | EW |
| M22_07 | 17.87 | 0.11 | 18.50 | 0.35568 | 0.00005 | Ell/BY |
| M22_08 | 18.70 | 0.20 | 19.74 | 0.32725 | 0.00003 | Ell/BY |
| M22_09 | 17.93 | 0.16 | 18.90 | 1.4791 | 0.0007 | Ell/BY |
| M22_10 | 17.32 | 0.32 | 18.47 | 5.250 | 0.003 | Ell/BY |
| M22_11 | 19.85 | 0.16 | 22.14 | 0.066226 | 0.000005 | Ell(?) |

be needed to obtain individual membership probabilities for each of the detected variables.

**Acknowledgments.**

We would like to thank Alex Schwarzenberg-Czerny and Grzegorz Pojmański for providing some useful software which was used in this project. We are grateful to Andrew Dolphin for helpful hints on the HSTphot package. It is also a pleasure to thank Stefan Mochnacki for remarks on the draft version of this paper.

This work is based on observations with the NASA/ESA Hubble Space Telescope, obtained from the Data Archive at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. These observations are associated with program #7615.

JK was supported by the Polish KBN grant 5P03D004.21.

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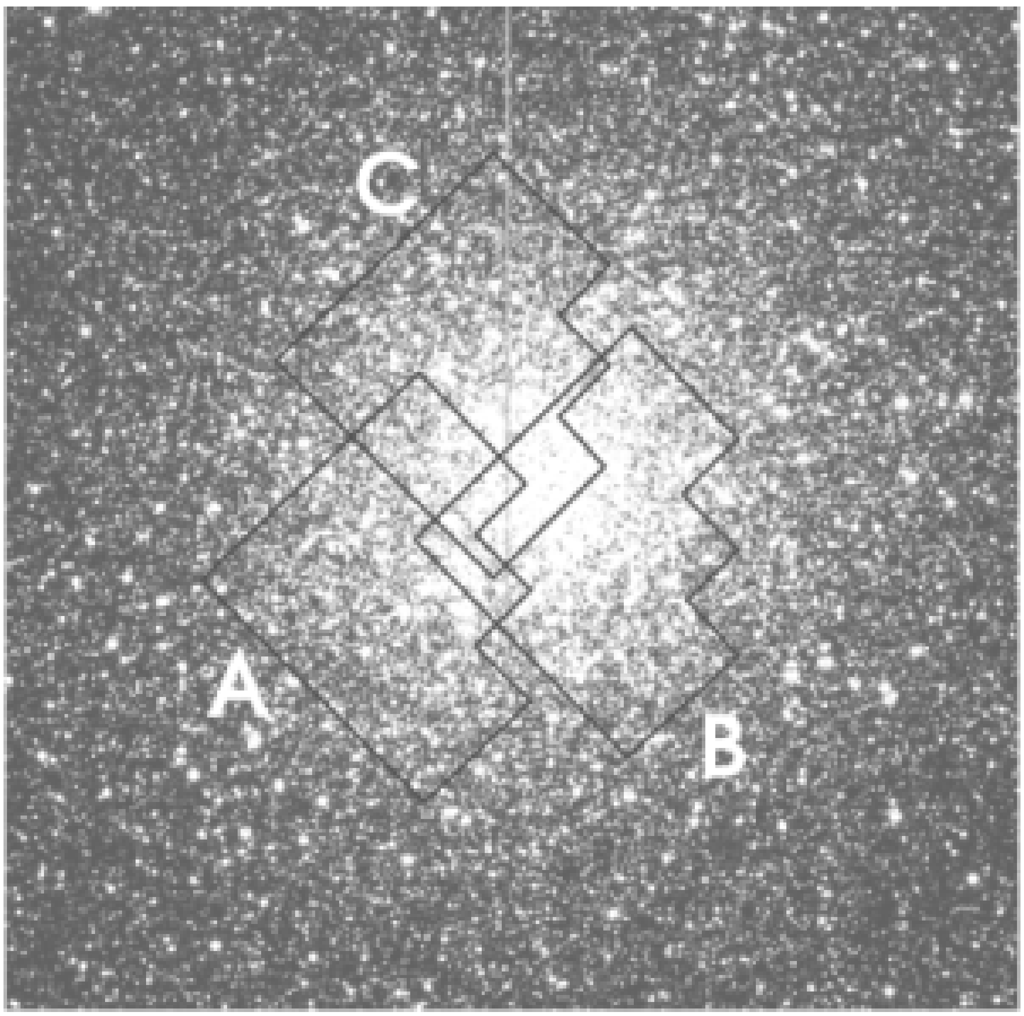


Fig. 1. The three HST fields in M22 overlaid on the ground-based image. East is to the left and South is up.

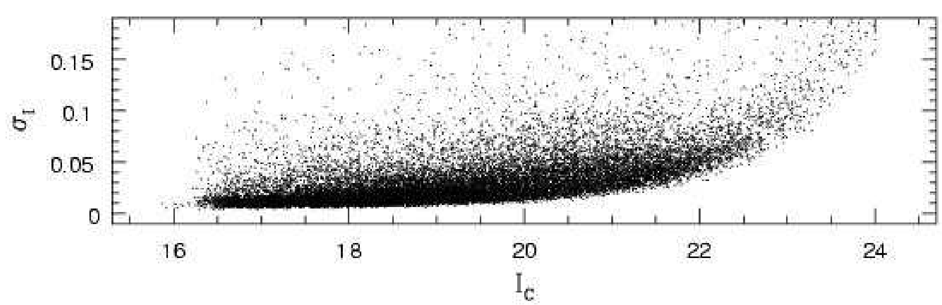


Fig. 2. The $rms$ for stars from field B as a function of $I_C$ magnitude.

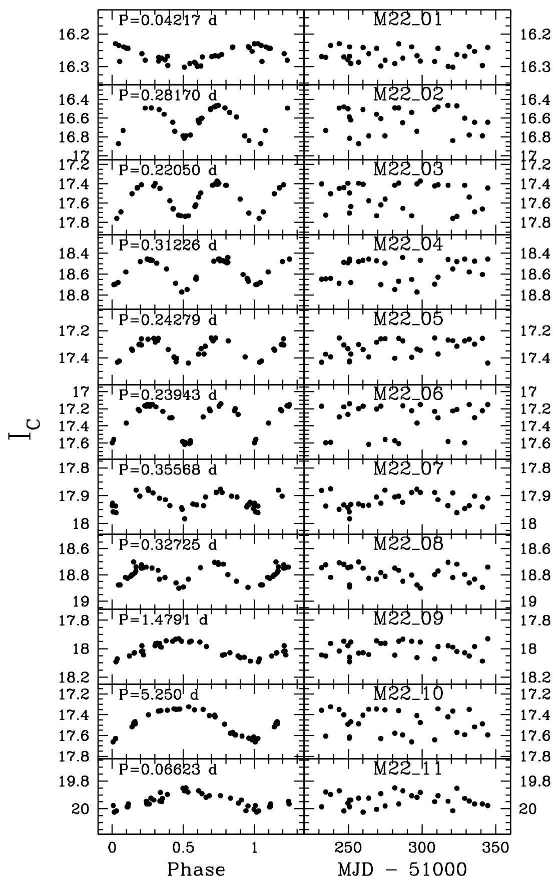


Fig. 3. Phased and time-domain (right panel) *I*-band light curves for the 11 detected variables in the field of M22.

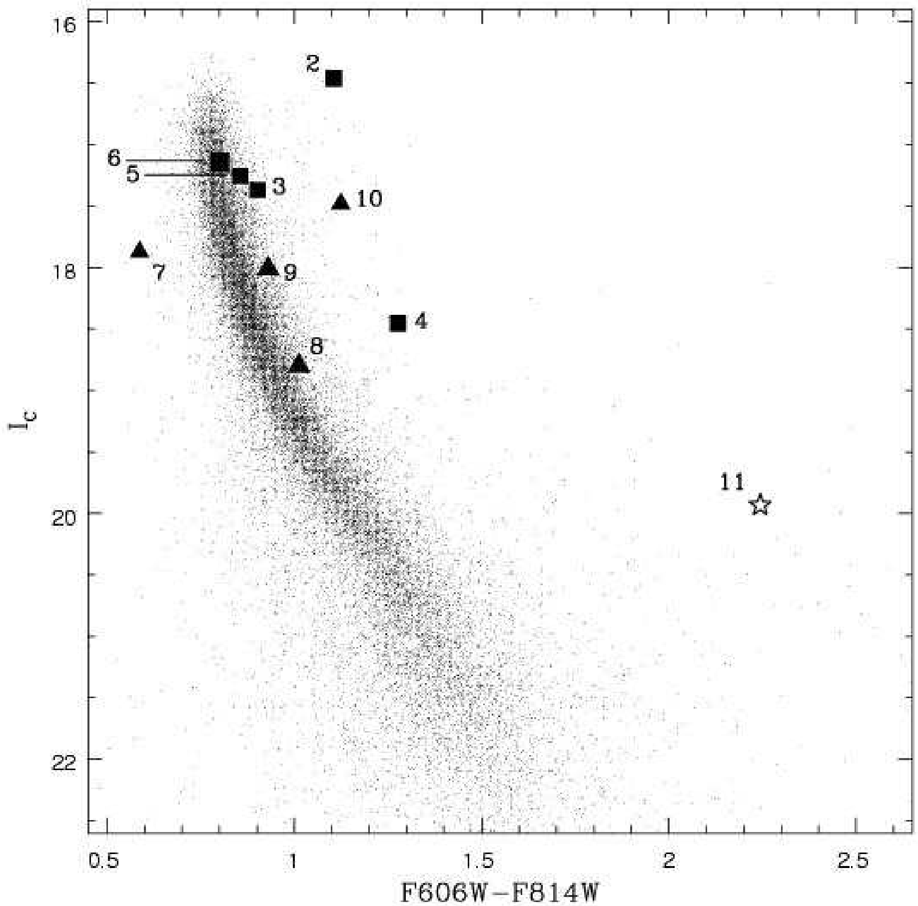


Fig. 4. Location of detected variables in the color-magnitude diagram of M22 (field B) for all four WFPC2 detectors. Squares denote EW systems.